Directional Beaming from a Corrugated Row of Holes at the End of an EBG Crystal

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Abstract

In this paper, it is shown how a corrugated row of holes can be used as a leaky wave antenna to radiate a broadside directional beam. The interface of a square lattice of metal vias, which has a bandgap around 30 GHz, is modified by adding a row of holes to excite a surface mode. The surface mode is coupled to a leaky mode which radiates into free space by corrugating the holes. The radiation pattern of the corrugated row of holes was calculated to show its directivity and radiation efficiency.

1. Introduction

Electromagnetic band gap (EBG) structures are artificial periodic structures prohibiting the propagation of electromagnetic waves of certain polarizations at certain frequencies and directions. These periodic structures are known as photonic band gap (PBG) or photonic crystals in optics community and have been used for controlling light propagation which led to the development of novel optical devices [1].

As it was shown in [2] a square lattice of metal vias was added to a triangle lattice of EBG waveguide to prevent the leakage inside the lattice when it is illuminated by a plane wave. This EBG waveguide is used to design a spatial power combiner which receives the signal from free space and reradiates it into free space after being amplified. In this paper we will show how a directional beam can be achieved by periodic modulation of the interface structure with the free space. In optics, it has been demonstrated that the optical transmission through a single subwavelength aperture made on a thick metallic film can be enhanced significantly when the surrounded surfaces are periodically corrugated [3]. This enhanced optical transmission is caused by the surface modes along the interface between the metal and free space. The electromagnetic response of EBG materials is similar to the response of metals for frequencies within its band gap. This feature, in addition to the existence of surface wave modes at the interface of EBG structure and with appropriate crystal termination can be exploited to enhance collecting and radiating the guided wave of the EBG waveguide. The modulated interface structure was analyzed using the Brillouin diagram to improve its radiation efficiency.

2. Surface Mode Excitation

A square lattice of metallic vias was designed [2] and added to the triangular lattice EBG waveguide to prevent the incident plane wave from penetrating through the triangular lattice. The termination surface of the square lattice can be modulated in a periodic fashion to support surface modes along the interface between the EBG structure and free space. This modulation can be done by adding a row of holes. The surface mode dispersion diagram was forced to fall within the band gap of the square lattice of metal vias by adjusting the unit cell size and the hole radius for the row of holes.

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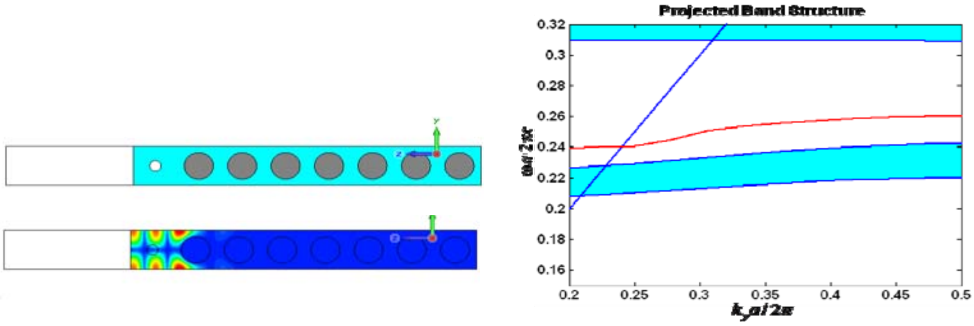
The unit cell of the square lattice of metal vias terminated by a hole is shown in Fig. 1 (a). Periodic walls parallel to the z-axis were placed at the periphery of the unit cell for the calculation of surface wave dispersion characteristics. The cell size ($a_{interface}$) and hole radius to cell size ratio ($r_{interface}/a_{interface}$) are set to 3.402 mm and 0.13 respectively to push the surface mode into the 30 GHz band. The ratio of metal via radius to a unit cell size should be modified to 0.34 in order to maintain the same bandgap as the original triangular lattice EBG crystal. Fig. 1 (a) shows the unit cell and the E-field pattern of the surface mode at its termination surface along y-direction.



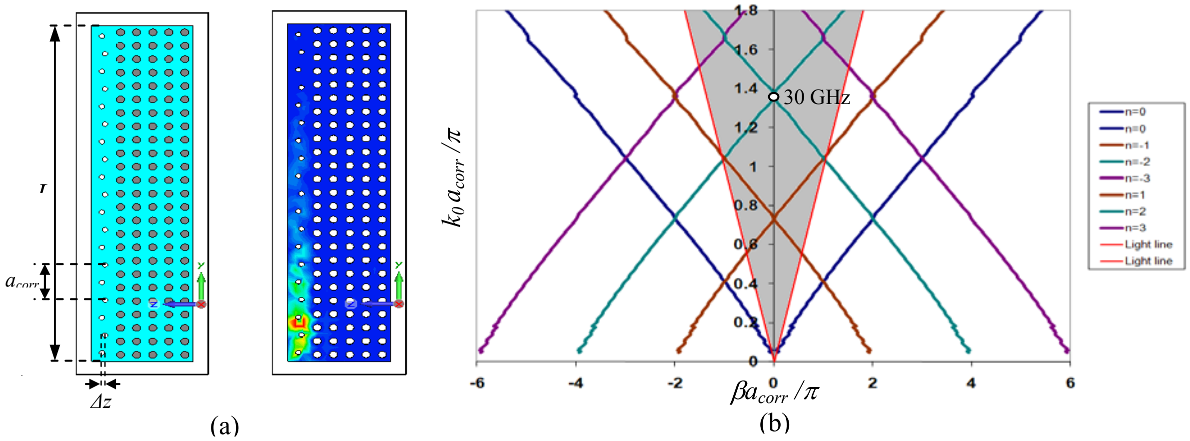
(a) (b)

Fig. 1 (a) The unit cell and E-field pattern, and (b) a projected band structure of the surface mode

The projected band structure of the surface mode was calculated based on the above unit and shown in Fig. 1 (b). The surface mode (red line) is located out of the light cone and within the bandgap of the EBG crystal as well. The fields therefore decay in both directions, free space and EBG crystal. The surface mode has a normalized frequency of 0.26 which corresponds to a frequency of 30 GHz at a wavenumber k_y equals to π which agrees with the results of E-field pattern shown in Fig. 1 (a). The flatness of the surface mode at the symmetry point ($k_z = \pi$) is due to the periodicity of the structure.

3. Directional Radiation at the Output of the EBG Waveguide

A row of holes which was designed in the previous section can be attached to the EBG waveguide to couple the guided wave in the PBG channel to a surface wave along its termination surface. Since this surface mode is outside the light cone as shown in Fig 1 (b), it can not be coupled to a radiation mode. The attached row of holes is ought to be modulated in periodic fashion to achieve the coupling of the surface mode supported by the interface structure to the continuum of radiation modes in free space. Such a modulation can be realized by corrugating the row of holes.



(a) (b)

Fig. 2 (a) A corrugated row of holes at the end of the EBG crystal, and (b) k_0a_{corr}-βa_{corr} diagram of structure

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The corrugation of the holes at the interface of the EBG lattice can be achieved by shifting every second hole a depth of Δz = 0.5 mm in the z-direction, thus obtaining a corrugation period $a_{corr} = 2\times a_{interface}$, as shown in Fig. 2 (a). By doing this, the periodicity of the interface structure can be adjusted to move the dispersion curve of the propagated mode into the light cone to transform it to a leaky mode.

As the corrugated row of holes is periodic along y-direction with a period a_{corr} , the k_0a_{corr}-βa_{corr} diagram, which shows spatial harmonic curves, can be calculated from the phase of S_{21}, $\phi_{S_{21}}$ [4]. As the spatial harmonics of the corrugated row of holes enter the fast-wave region, which is shaded in Fig. 2 (b), the structure behaves as a leaky wave antenna. The angle of radiation of this leaky wave antenna with respect to the broadside (θ) can be calculated by $\sin\theta = \beta / k_0$. Since $k_0a_{corr} = 1.35\pi$ which is equivalent to frequency of 30 GHz occurs at $\beta a_{corr} = 0$, the angle of the main beam (θ) is equal to 0, and the beam direction is broadside with respect to the *z*-axis. It is obvious from the calculated radiation pattern, shown in Fig. 3, that the angle of the main beam is 0 with respect to the broadside which agrees with the result of the calculated k_0a_{corr}-βa_{corr} diagram.

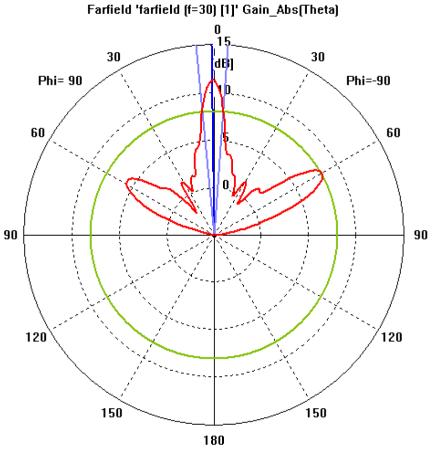

Fig. 3 A simulated radiation pattern of the corrugated row of holes

4. Conclusion

A surface mode was excited at the interface of a square lattice of metal vias by adding a row of holes at the interface between the EBG structure and the free space. The corrugated row of holes was exploited to achieve the coupling of the surface mode supported by the interface structure to a leaky mode which can radiate into free space. Dispersion diagram k_0a_{corr}-βa_{corr} was calculated and utilized to design a corrugated row of holes which has a directional main beam along 0° (broadside). The calculated radiation pattern agrees with the analysis of the k_0a_{corr}-βa_{corr} diagram.

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